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INVESTIGATION IN TEMPERATURE CONTROL OF HYDRAULIC SYSTEMS IN ROUGH TERRAIN FORK TRUCKS

Irving Tarlow
Quartermaster Research and Engineering Command
Natick, Massachusetts

The problem of overheating in hydraulic systems of mobile equipment has not been given full consideration nor have the ramifications been completely understood by designers of such equipment. The effect of excessive heat can be injurious to the operator, the equipment and to persons in the proximity of the equipment.

In industrial applications of hydraulic equipment, space has not been one of the problems. Hydraulic systems designed on this premise provided for a reservoir tank of sufficient fluid capacity to dissipate the heat or a system in which a heat exchanger has been incorporated.

This approach cannot be applied to mobile hydraulic systems. Space is not available for large fluid reservoirs or heat exchangers. The situation is usually more aggravated by the radiation of heat from the engine as well as crowding components of the system into a small enclosed area in which the heat from the system itself has to be considered.

The designer, evaluating the heat effect, takes into consideration the type of operation for which the equipment was intended. For commercial materials handling equipment this approach has been for the most part valid. The hydraulic system is not taxed to the degree that heat has been a factor. Idle time between cycles has been sufficient to allow cooling of the fluid to a safe temperature level. However, in Military applications, where unloading operations are on a 24-hour per day basis and long road marches are a required operational feature, temperature control must be built in.

The condition of high fluid temperature was detected in an All Purpose Fork Lift Truck having a 6,000-lb capacity at 24-inch load center. This vehicle is a Military item presently in the supply system in large quantities. The purpose of this vehicle is to handle supplies, whether palletized, unitized or containerized, over rough terrain, in open storage areas and in all types of climatic environments as well as all types of terrain. This vehicle must be capable of operating under conditions of limited visibility, inclement weather and blackout and be capable of

negotiating open rolling and hilly terrain consisting of mud, snow and sand. In addition, this vehicle must also be capable of highway operations.

Prior to actual investigation and subsequent remedial action, the possible effects of the problem were analyzed. The analysis included but was not limited to:

- (1) The effect on humans.
- (2) The effect on the system.

The location of the operator's compartment is directly above the reservoir tank. Therefore, operator discomfort is a factor. Since the tank is mounted outboard of the chassis, personnel coming in contact with the tank surface could suffer burns. While either and both of the above are serious, far more important were the injuries and possible fatalities which could result from hydraulic line ruptures and component failures. The unleashing of hydraulic fluid which was under pressure of up to 1400 psi and whose temperature was in excess of 250 F is considered to be the most serious of those previously mentioned.

The second area to be considered in evaluating the effect of high temperature rise is the effect upon the system itself. Excessive temperatures of petroleum fluids will cause lubricating qualities to be reduced. For gear pumps whose shafts run in journal bearings, the design is such that the shaft "floats" on a film of oil so that there is no contact between the shaft and the bearings. Extreme heat will cause the film to break down. When this occurs, the shaft comes in contact with the bearing and causes galling and seizing. Galling and seizing will also occur when unequal expansion occurs between two parts of dissimilar material. Directional control valves are particularly susceptible to the problem of unequal expansion which causes spools to stick resulting in an inoperative system.

Petroleum fluid deterioration can have additional harmful effects upon the system. When a petroleum fluid deteriorates sludge forms, this sludge will be deposited on surfaces which are subjected to localized heating. Filters and lines become clogged and valves become stuck. If a sump filter is used in the reservoir tank and it should become clogged due to the formation of sludge, cavitation of the pump will in all likelihood result.

The particular hydraulic system on which the investigation was conducted is of the open center type and consists of a fixed displacement pump coupled to the engine input shaft. Fluid passes from the pump to a directional control valve and is then directed either to reservoir tank when no work is required or to a working cylinder.

It was necessary to first isolate the cause of excessive heating. A work cycle was devised based on a simulated field operation. This consisted of lifting a 6,000-lb rated load, transporting it to a new site, stacking the load and then returning to the starting position. Temperature was recorded in the reservoir tank approximately 2 inches from the bottom and 18 inches away from suction outlet.

Through observation, it was detected that the rise in temperature occurred during the transporting phase of the cycle. Temperature would drop during the work cycle and then rise again during transport. By analyzing the circuitry, it was determined that the heat rise was in all probability due to a restriction and further that this restriction was located in the directional control valve.

In order to substantiate the analysis, the directional control valve was by-passed and the fluid path was controlled so that it passed from the pump directly to the reservoir. This resulted in a substantial reduction in temperature and stabilization point in the system thereby validating the analysis.

The problem of controlling the fluid temperature became twofold:

(1) A method had to be devised by which vehicles already issued to the field could be modified quickly and economically and still permit satisfactory operation during the service life of the vehicle. (Service life is considered to last from 8 to 11 years for this type of equipment.)

(2) Redesign of the hydraulic system in order to produce specification changes which would permit future procurement of a vehicle capable of satisfying all of the operational requirements.

Prior to development of a solution, it was first necessary to establish acceptable operating parameters. To do this, the vehicle was instrumented to record reservoir tank temperature, pressure between pump and directional control valve and pressure on the return line between the control valve and reservoir tank.

Since the pump was of a fixed-displacement type directly coupled to the engine, the controlled variable became engine speed. The pump output in gallons per minute was determined at various engine speeds. After this, the back pressure in pounds per square inch at various flow rates (gpm) was determined for the directional control valve. The next step was to determine the acceptable back pressure and relative temperature rise limits. This was necessary since it already had been determined that 100 deg. temperature rise above ambient could be tolerated for the particular oil being used in the system and for areas of the world where the vehicle would be used. In order to ascertain, therefore, what back-pressure could be tolerated which would result in no more than 100 deg. temperature rise, the following tests were conducted:

The vehicle was operated at maximum engine speed until the temperature in the tank stabilized for a minimum period of 20 minutes. Engine speed was varied and successive runs at different speeds were made. Through observation and analysis of the stabilized temperature and back pressure, it was determined that the maximum open center pressure drops across the directional control valve should not exceed 100 psig.

In explanation of the above let me, at this time, cite a few of the specifics:

- a. The majority of test runs were made in low gear and at full engine rpm. This will reproduce all conditions anticipated during convoy with the exception of the cooling effect from a high velocity wind passing by the hydraulic tank. When tested in high gear at 25 mph, a 20 degree drop in maximum temperature below that of low gear was observed.
- b. Pump specifications required a minimum oil viscosity of 45 SSU. For the oil used in the system 45 SSU occurred at 200 F.
- c. All convoy runs were made with the engine side panels off. When the engine side panels were in place, the result was additional drop in stabilization temperature of 24 F.
- d. An additional factor which, although not measurable, and which has a direct bearing on the temperature is the nature of a convoy. Convoys have what is known as an accordion effect. At high speeds on long runs vehicles have a tendency to crowd together. When this happens, the line has to slow down and vehicles separate in order to

maintain proper spacing between them. When the fork lift truck slows down, engine speed decreases. The pump will circulate fluid at a lower rate and the oil will cool.

These factors just listed will permit safe operation in ambient temperatures up to 125 F when the temperature rise measured in the hydraulic tank with the transmission in lowest gear and engine at maximum governed speed is limited to 100 F.

While temperature could be used as the criterion to control the heat rise in the system, it is still necessary to provide the manufacturer with some guide for the selection of the components. Since it had been determined that temperature rise could be controlled by controlling the pressure drop across the main control valve, it became necessary to provide a tolerance for this factor. Analysis of the data indicated that the maximum allowable pressure which would maintain the 100 degree rise in hydraulic tank was 100 psig. This additional information would control the maximum amount of restriction which could be tolerated in the main control valve.

The limitations placed on temperature and pressure would suffice for specification requirements. However, it was still necessary to modify the equipment already issued to the field.

While there are many possible solutions to correcting the deficiency in the equipment, only four approaches were tested. These were:

a. Redesign of the hydraulic tank. As previously stated, space was at a premium, therefore little could be done in this area of increasing the reservoir volume. However, it was possible to redesign the tank so that the flow of fluid from discharge to suction would be along the tank walls thereby taking maximum advantage of surface radiation. While there was a temperature reduction, it was not of significant magnitude by itself to control temperature rise.

b. Control the flow into the directional control valve. By dividing the fluid as it was delivered from the pump it was possible to control the amount of fluid delivered to the valve. Excess fluid could be shunted directly to the reservoir tank. By controlling the amount of fluid which passed through the control valve it was possible to control back pressure.

c. Replace the hydraulic pump. By varying engine speed, it was possible to control the amount of fluid into the directional control valve. However, at a point where back pressure was reduced sufficiently and temperature stabilized within acceptable limits, engine speed was reduced to the point where other characteristics were affected materially enough to render the vehicle not operationally suitable. The effect, hydraulically, could be achieved by replacing the pump with one having smaller delivery rates.

d. Replace the directional control valve. This is the most obvious of those listed. Since the valve was the cause of heat by having internal porting such that flow was being restricted, it could be replaced with another model which had larger porting with decreased restriction.

It should be mentioned that there are various combinations of the four listed which could also offer satisfactory solutions. Each of the four solutions has disadvantages and by themselves do not offer the ideal solution. When certain combinations are made the disadvantages of each by itself are often nullified.

Since a number of vehicles had already been issued, other factors had to be taken into consideration and trade-offs had to be made before the final solution was agreed upon. Some of the factors were:

a. Economy: The pumps and directional control valves are costly units in the price range upwards of \$300 each. Installation costs for directional controls would be high as it required extensive repiping.

b. Parts availability: The parts required for the item would have to be available within a reasonable time frame since operation of these vehicles affected our combat readiness.

c. Labor availability: The skills required to apply the remedy would have to be available at the level at which the actual work would be done.

d. Simplicity of installation: Consideration had to be given to the desired echelon which would apply remedy. The world wide dispersion of vehicles dictated that the remedy should be applied at the lowest possible echelon in order to avoid massive transportation costs to any single location. Therefore, if the remedy could be readily applied without the need of skilled labor, the echelon would necessarily be a low one.

e. Ease of maintenance: This item was a basic consideration. The parts required to correct the deficiency could not create an added burden on those responsible for the maintenance of the item.

Applying the factors just listed to the possible solution, it was decided that the application of a by-pass and flow divider type valve which would govern the flow from the pump to directional control valve on a priority basis would satisfy these requirements.

a. Economy: The complete installation would approximate 20% of the cost of installation of either a new pump or new directional control valve.

b. Parts availability: The item was an off-the-shelf item and readily available.

c. Labor availability: The item could be applied by an ordinary mechanic.

d. Ease of installation: The unit could be sent to the field in kit form and would require only three connections.

e. Ease of maintenance: The operation of this valve is relatively simple -- fluid from the pump goes to the inlet of the divider and through a fixed orifice in a sliding valve. The oil passing over the orifice creates a pressure differential that pushes the valve against a spring. Since the spring exerts essentially a constant force, the pressure differential is constant and the flow to create the differential is constant. If the flow through the orifice tends to increase, the pressure differential is increased and the valve moves to uncover a by-pass port. The size of the orifice may be selected for any desired amount and can be controlled within one gallon per minute. Due to the simplicity of this type valve, no additional maintenance burden would result from its installation.

Testing of this valve against the operational requirements indicated that concessions in this area had to be made as follows:

a. Engine speed had to be governed down slightly.

b. Back pressure up to 140 psig would have to be tolerated resulting in

c. A temperature rise up to approximately 143 F.

As for future procurement, the design of the hydraulic system has been changed so that a new pump and directional control valve will be used which during testing met the 100 psi back pressure and 100 F temperature rise limitations.